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A DISTRIBUTED PLANNING CONCEPT FOR SPACE STATION PAYLOAD OPERATIONS

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ABSTRACT

The complex and diverse nature of the payload operations to be performed on the Space Station requires a robust and flexible planning approach. The planning approach for Space Station payload operations must support the phased development of the Space Station, as well as the geographically distributed users of the Space Station. To date, the planning approach for manned operations in space has been one of centralized planning to the n-th degree of detail. This approach, while valid for short duration flights, incurs high operations costs and is not conducive to long duration Space Station operations. The Space Station payload operations planning concept must reduce operations costs, accommodate phased station development, support distributed users, and provide flexibility. One way to meet these objectives is to distribute the planning functions across a hierarchy of payload planning organizations based on their particular needs and expertise. This paper presents a planning concept which satisfies all phases of the development of the Space Station (manned Shuttle flights, unmanned Station operations, and permanent manned operations), and the migration from centralized to distributed planning functions. Identified in this paper are the payload planning functions which can be distributed and the process by which these functions are performed.

1. INTRODUCTION

The key to any successful project, be it a complex space mission or a simple family picnic, is proper planning and preparation. The planning approach used must be tailored to meet the specific needs of the problem at hand. The Space Station payload operations planning problem is considerably different from the payload operations planning problem associated with current Shuttle missions. The characteristics of this problem which make it so very different are: large numbers of geographically distributed payload users (e.g., users in the United States, Japan, Canada, Europe, etc.), multiple operations control centers, continuous operations, diverse and dynamic payload complements, and a desire for operational flexibility. With these characteristics in mind, it is crucial that a payload operations planning concept be developed which meets the needs of the payload user community and the Space Station program.

2. PLANNING CONCEPT

Because of the diverse and dynamic payload complement, no one organization will have the knowledge and expertise required to perform all of the detailed planning. Since the knowledge and expertise is spread across the various organizations and users, it makes sense to distribute the planning as well. While there are many possible ways of supporting distributed planning, the hierarchical distribution of resources appears to be the approach which is best suited for Space Station payload operations planning. An overview of this concept is provided in the following sections which describe the architecture, resource envelopes, and planning process. The architecture and resource envelopes are discussed first to provide the reader with a basis for understanding the planning process. Rather than expressing this concept using Space Station specific terminology, the concept is described in general terms which can be applied to other planning problems.

2.1 Architecture

Figure 1 provides an overview of the architecture which supports this approach. This architecture consists of various levels of planning, where the functions of a particular level are performed by one or more organizations.

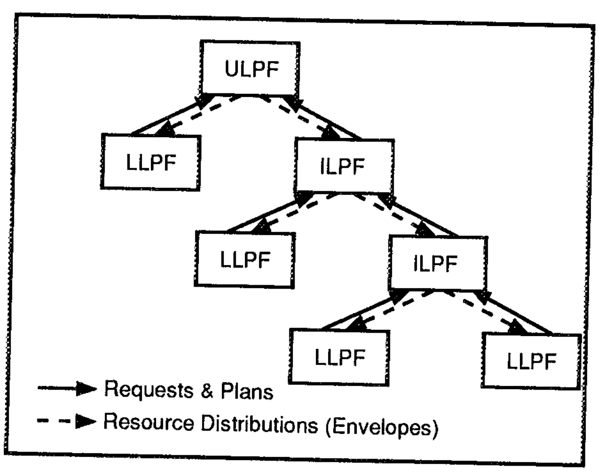

Figure 1. Architecture

In general, there are three basic levels of planning: 1) Upper Level Planning Function (ULPF), 2) Lower Level Planning Function (LLPF), and 3) Intermediate Level Planning Function (ILPF).

The ULPF represents the controlling authority and is ultimately responsible for the integrated plan of payload operations. There is only one ULPF, although there may be many organizations which support its functions. The LLPF represents the individual users of the Space Station. These individuals have specific payload operations which need to be scheduled, and are in competition with one another for the limited resources available to support those operations. The ILPF represents the organization or organizations which serve as the interface between the ULPF and the LLPF. In most cases, the ILPF represents the sponsoring organization or country of the users. In cases where there is no ILPF organization, the LLPF interfaces directly with the ULPF. There may be multiple ILPF levels, where one ILPF organization exists to serve the ILPF organizations which fall under its authority. Refer to Figure 1 for a pictorial representation of this architecture and the relationships between the ULPF, ILPF, and LLPF organizations.

The basic premise of this concept is that resources are distributed in a manner which allows for concurrent planning at each level in the architecture. Requests for resources are passed from the LLPF upwards through the ILPF level(s) to the ULPF. The ULPF, taking into account all of the requests for resources, distributes the available resources to the ILPF. Each ILPF then distributes its resources to the level below it, either another ILPF level or the LLPF. At the LLPF level, the users develop plans within their resource distributions and pass those plans back up through the path to the ULPF. Each level, by having a view into all of the requests for resources at its level, can ensure an equitable distribution of resources to best satisfy the needs of its users. The flow of this information from one level to the next is depicted in Figure 1.

2.2 Resource Envelopes

Resources are distributed to the planning levels in the form of resource envelopes. A resource request is the *time-independent* distribution of the magnitude of a resource over time. In contrast, a resource envelope is the *time-dependent* distribution of the magnitude of a resource over time. The development of envelopes involves assigning a resource request to a specific time period. Figure 2 shows an example of a resource envelope. Resource envelopes are created for each resource that constrains planning. For example, there are envelopes for power, data, crew, etc. The resource requirement shown in Figure 2 represents a power profile required to perform an operation or group of operations. The ILPF or LLPF organizations may request a resource in excess of the actual requirement to allow for the desired operational flexibility. The resource requests are submitted to the appropriate planning level for resource envelope development.

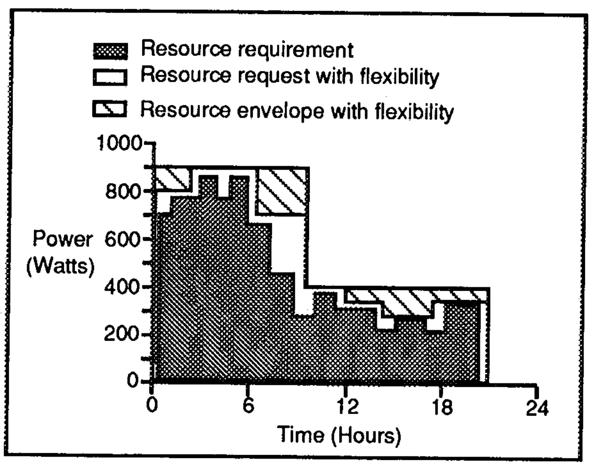

Figure 2. Resource Envelope

Resource envelopes are developed to satisfy resource requests within the resource availabilities and other constraints. The resource envelope defines a profile that is greater than or equal to the resource request. Additional flexibility may be added to the resource request to simplify the resulting profile. Once a resource envelope is developed and distributed to the appropriate level, additional envelopes can be created at that planning level based on the resource availability profile provided in its resource envelope. These envelopes are created in a manner which ensures that no overbooking of the resource occurs. Figure 3 illustrates the distribution of resource envelopes.

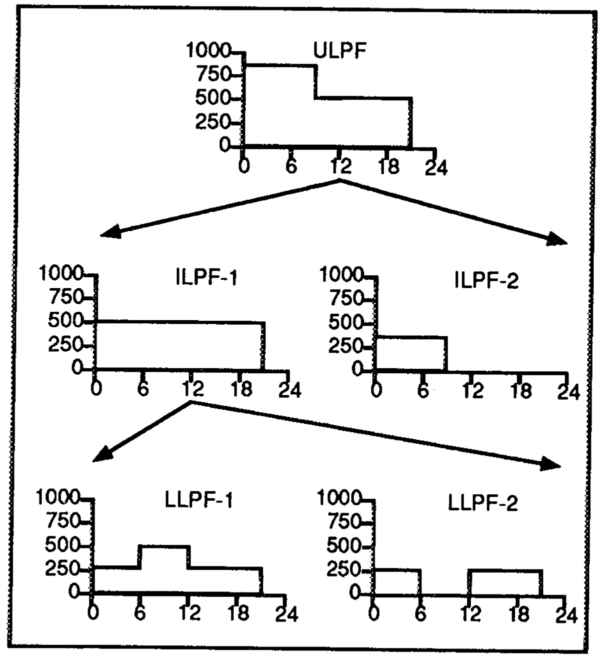

Figure 3. Envelope Distribution

2.3 Planning Process

The process for developing payload operations schedules is usually tailored to the environment in which the planning is performed. Problem characteristics, planning cycles, unique product requirements, functional interfaces, and planning software capabilities factor into the definition of the planning process. The distribution of planning responsibilities will also significantly affect the design of the planning process. The Space Station payload planning process will therefore differ somewhat from the processes used for Space Shuttle/Spacelab payloads or for unmanned free-flyer payloads. However, there are also similarities. The Space Station planning process must support manned operations, like Shuttle/ Spacelab, as well as continuous operations and unmanned periods, like the free-flyers.

The key to developing a distributed planning process is that all planning processes are built upon the same fundamental set of planning functions:

- *Constraint Definition*
  Defines all constraints on scheduling, including the scheduling horizon, groundrules, definition of resources and system configurations, resource availability profiles, etc. Resources may represent physical objects, such as equipment; systems services, such as power; or environmental conditions, such as microgravity or orbital daylight.
- *Requirements Definition*
  Defines the requirements of each operation to be scheduled. These requirements may include resource usage profiles, temporal relationships to other operations, and performance requirements (number of performances of the operation and their required distribution over time).
- *Scheduling*
  Produces conflict-free schedules which satisfy the scheduling requirements within the defined constraints.
- *Product Generation*
  Produces integrated payload plans and data which can be used to analyze and/or execute the schedule.

The major difference between a centralized planning process and a distributed one is *who performs* each of the functions.

Typically, the requirements definition function is performed by those organizations or individuals who have in-depth knowledge of the operations to be scheduled, such as the users who sponsor the payloads on the Space Station. In the planning architecture discussed earlier, these organizations and/or individuals would belong to the LLPF. In a centralized planning environment, the other planning functions are performed by a single centralized authority, represented in the planning architecture by the ULPF. Figure 4 represents a typical centralized planning process.

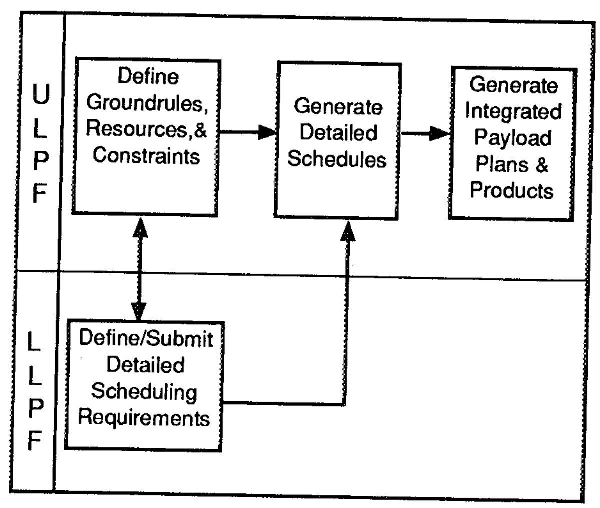

Figure 4. Centralized Planning Process

In a distributed planning environment, the responsibility for performing each of the planning functions may be distributed across the entire hierarchy of payload planning organizations (ULPF, ILPF, LLPF), as discussed in the architecture section. The degree to which the planning functions can be distributed depends on many factors, including the abilities and desires of the various organizations to actively participate in the planning process.

Figure 5 depicts a distributed planning process with each of the planning functions fully distributed across the various planning levels (ULPF, ILPF, LLPF). A discussion of this process follows. To simplify the discussion, Figure 5 is shown with exactly one ILPF level between the ULPF and LLPF. The process can easily be modified to accommodate an architecture with multiple ILPF levels or no ILPF level at all. It will also support centralized planning if the ULPF organization performs all of the planning functions except requirements definition, which must be done by the LLPF.

The *Constraint Definition* function may be distributed if there are particular resources or groundrules which are unique to a single payload (LLPF) or group of related payloads under a common ILPF organization. For example, a group of life science payloads under a common ILPF might share the use of a life science glovebox. Such constraints may be defined at the appropriate ILPF or LLPF level. Space Station systems services, crew, and all other constraints which apply across multiple ILPF organizations must be defined and controlled by the ULPF. Although constraints may be defined at any level, it is extremely important that all organizations are planning against a common and consistent set of constraints. Visibility into all levels is required to ensure that conflicts in constraint definition do not occur. For example, the creation of three distinct resources with the name "Glovebox" by different organizations would complicate the schedule integration function later in the process.

As in the centralized process, the *Requirements Definition* function is primarily performed by the LLPF. In the centralized process, the LLPF submits detailed scheduling requirements which the ULPF can utilize in scheduling and product development. In a distributed process, however, the LLPF submits requests for resources within which it can perform its own detailed scheduling. As

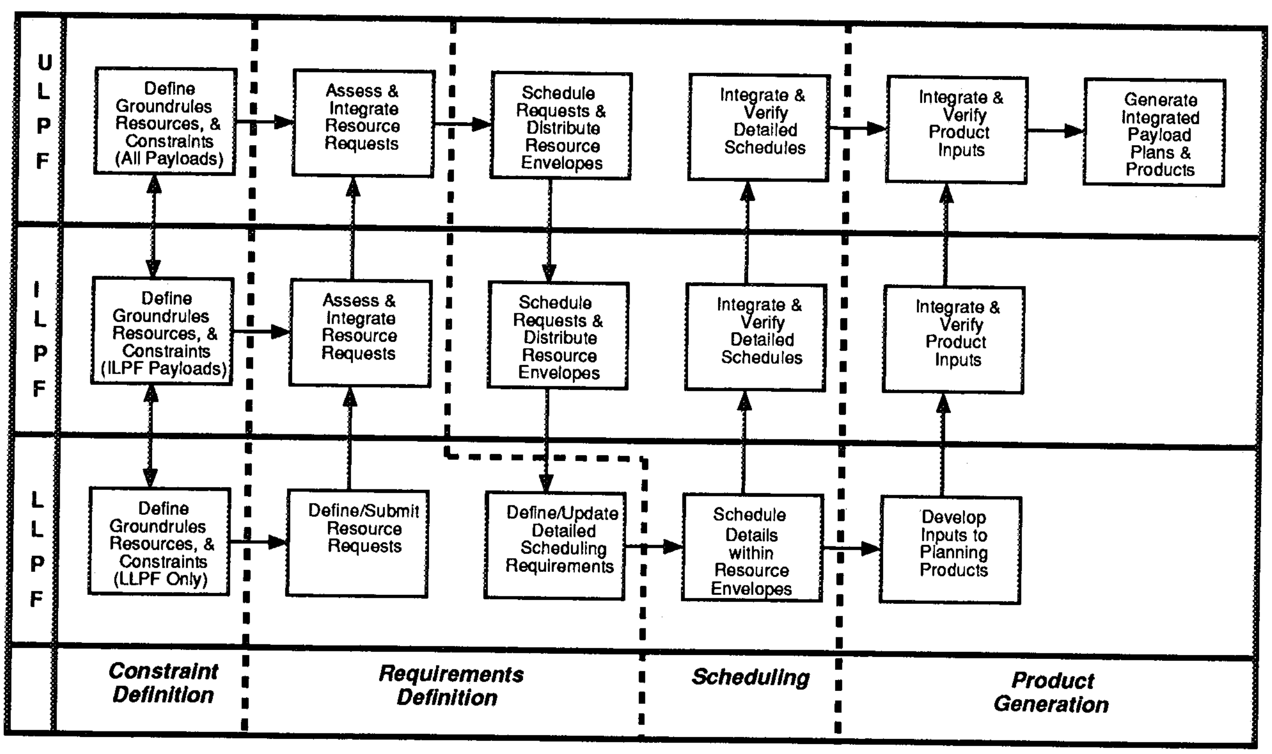

Figure 5. Distributed Planning Process

was discussed in the section on resource envelopes, a resource request may represent the exact requirements of a specific operation, or it may grossly define a set of resources which accommodates the requirements of one or more operations. A gross resource request will provide the LLPF with any desired flexibility in the detailed scheduling step of the process.

Each ILPF collects and assesses the resource requests submitted by its associated LLPF organizations. Conflicts between LLPF requests are resolved at this point. Based on its objectives and priorities, the ILPF may choose to forward any or all of the individual LLPF resource requests to the ULPF. The ILPF may also choose to merge multiple LLPF resource requests into larger ILPF resource requests. This may provide the ILPF with some desired flexibility in the scheduling step of the process.

When all of the ILPF/LLPF resource requests are submitted, the ULPF is ready to begin the *Scheduling* process. By having visibility into all users' needs (via the resource requests), the scheduling process can ensure an equitable distribution of resources across the entire payload complement. First, the ULPF schedules the integrated set of resource requests against the defined constraints. From this integrated schedule, resource envelopes are then constructed for each ILPF. These envelopes may contain resources in excess of what was requested by the ILPF. A key aspect of this concept is that the sum of the distributed resource envelopes created at any level cannot exceed the resource availabilities (no overbooking of resources allowed). This ensures that the detailed schedules created at lower levels will not produce constraint violations when integrated together. Note that the ULPF may only distribute resource envelopes for those resources which are under its control.

Next, each ILPF follows a similar process to divide its resource envelopes into individual LLPF resource envelopes. Any resources under the control of the ILPF may be distributed at this time.

Detailed scheduling of specific operations is then performed by the LLPF within the resource envelopes assigned by the ILPF. Prior to scheduling, the LLPF completes the *Requirements Definition* process for its operations by defining/updating the detailed scheduling requirements.

The last step in the *Scheduling* process is the integration of the independently developed detailed schedules. Integration is performed in an upwards fashion through the ILPF to the ULPF. Each planning level verifies that the detailed schedules it integrates are compatible with the appropriate resource envelopes. As part of the integration function, the ULPF may perform any additional planning tasks required to finalize the integrated schedule of payload operations.

The *Product Generation* function may also be distributed to a certain extent. Some additional information, not required for scheduling, must be associated with the payload schedule in order to generate the products which are used by the onboard crew, onboard software, and ground controllers to execute the schedule. Examples of these product inputs include identification of the detailed procedures to be executed for each scheduled operation, and associated notes. Since the LLPF has the most intimate knowledge of the payload operations and procedures, it builds the product inputs, which are then integrated by the ILPF and ULPF for inclusion in the final products.

3. ANALYSIS AND EVALUATION

As with any complex concept or process, there are a number of strengths and weaknesses associated with the distributed planning concept described in this paper. A discussion of the known advantages and disadvantages follows.

3.1 Advantages

The distributed planning concept provides a number of advantages which make it particularly attractive as a solution to the Space Station payload operations planning problem. Following is a brief summary of these advantages:

- Reduces the operations costs of the ULPF organization through the increased participation of the ILPF and LLPF organizations.
- Provides operational flexibility at the appropriate level of fidelity through the use of resource requests and resource envelopes. This flexibility results in a plan which is better able to accommodate changes during plan execution.
- Places responsibility for planning at the level where the knowledge and expertise exists. The end users (LLPF) are active participants in the process and are not simply viewed as data providers.
- Results in the production of conflict-free plans through the use of resource envelopes which do not allow for the overbooking of resources.
- Supports the transition from centralized to distributed planning, as well as a mixture of both centralized and distributed concepts. The planning process remains fairly stable regardless of the number of organizations performing the various planning functions.
- Ensures equitable distribution of resources among the payloads through visibility into the integrated set of resource requests.

3.2 Disadvantages

The distributed planning concept also has a number of disadvantages associated with it. Many of these disadvantages are a direct result of the distribution of planning functions and would probably manifest themselves in other distributed planning concepts. Following is a brief summary of these disadvantages:

- Increases operations costs to the ILPF and LLPF organizations due to their more active role in the planning process.
- Results in less efficiency in the planned utilization of resources. The flexibility built into the resource requests and resource envelopes results in the scheduling of resources which may not actually be utilized.
- Results in longer planning cycles due to the active involvement of all levels in the planning process. Sufficient time must be provided to allow each level to perform its required functions, as well as to account for the transfer of information from one level to the next.
- Requires a significant amount of coordination to define the planning constraints. The success of this concept depends on all of the various organizations using a well defined and consistent set of planning constraints.
- Results in numerous and complex interfaces to support the distribution of the planning functions. Organizations involved in the process will be geographically distributed and will be working in facilities which may or may not be similarly equipped.
- Requires a rigorous configuration management process to ensure that all organizations are using the most current

data and that changes to the data are only made by authorized organizations.

4. CONCLUSIONS

The complex and diverse nature of the payload operations to be performed on the Space Station will require a change in the current payload operations planning philosophy. The unique characteristics of the Space Station payload operations planning problem drive the need for a distributed payload operations planning concept.

The key to a successful payload operations planning concept is to develop an approach which will meet the needs of the payload user community and the Space Station program. The authors believe the distributed planning concept presented in this paper provides a robust and flexible planning approach which will support the phased development of the Space Station, accommodate a large number of geographically distributed users, accommodate diverse and dynamic payload complements, as well as provide for operational flexibility. There are significant benefits to be gained with this concept if the Space Station program is willing to accept the disadvantages. The authors feel this is a viable concept which is being actively pursued for implementation. This concept will need to be revisited to accommodate changes as the Space Station program evolves. Also, it is acknowledged that certain functions associated with this concept will require further study and development.

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